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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Phosphorus has been identified as the nutrient element most limiting to the growth of algae in Lake Erie. In addition, nutrient loadings by tributaries are a major source of phosphorus to the lake; of this load, the diffuse load, and especially the agricultural diffuse load is a major component of the total P input to Lake Erie.

The particulate P load carried by a stream has several sources: native soil P, P from fertilizer, manure, and waste, P from crop residues and detritus. The

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bulk of sediment-P, however, is native soil P except where additions of manure have been heavy over many years.

In light of these issues, a study was initiated to investigate levels of available-P in agricultural soils in the Lake Erie drainage basin. This report is concerned with two major objectives:

a. To survey actual field levels of available P in a county in Ohio and compare these with published soil test summary data for the same area; and

b. To determine if similar data were available in other Lake Erie Basin states and to determine if soil test methods and recommendations varied significantly from state to state.

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(6) **Levels of Plant Available Phosphorus in Agricultural Soils in the Lake Erie Drainage Basin**

Project Report

Agronomy Department

Ohio Agricultural Research & Development Center

(10) Terry J./Logan

Project Leader

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Information provided by Dr. Daryl Warncke, Michigan State University, and by Drs. Tom Bates and Murray Miller, University of Guelph is also gratefully appreciated.

INTRODUCTION

Phosphorus has been identified as the nutrient element most limiting to the growth of algae in Lake Erie. In addition, nutrient loadings by tributaries are a major source of P to the Lake; of this load, the diffuse load, and especially the agricultural diffuse load is a major component of the total P input to Lake Erie. Phosphorus reacts strongly with mineral soil particles, and, as a result, is sparingly soluble in water which contains sediment. Sediment-bound P can account for >90% of the total P load in the stream.

The particulate P load carried by a stream has several sources: native soil P, P from fertilizer, manure and waste, P from crop residues and detritus. The bulk of sediment-P, however, is native soil P except where additions of manure have been heavy over many years. Normal fertilizer P additions increase the total P content of soil only slightly, but may affect the extent to which soil P is released into solution.

Modern phosphate fertilizers such as triple superphosphate ($Ca(H_2PO_4)_2$), monoammonium phosphate ($NH_4H_2PO_4$) or diammonium phosphate ($(NH_4)_2$ HPO_4) are completely water soluble. When added to the soil, they react with soil constituents and a high percentage of the fertilizer-P is rendered insoluble. Part of the fertilizer-P plus some soil-P and previously applied fertilizer-P are held weakly enough by the soil that it can be extracted by plant roots. This portion of the total soil-P is referred to as "plant available-P" or "available-P", and usually constitutes 5-10% of the total-P.

Soil test procedures used today employ mild chemical extraction to remove part of the available-P. The amount extracted is then correlated with plant P uptake and crop yield. Research has determined for each extractant and each crop the levels of available-P at which crop growth is limited and when response to fertilizer-P can be expected. Research has also determined the amounts of fertilizer-P that must be added to raise available P levels.

In many mineral soils of the U. S., it takes a fertilizer-P application of 5-10 kg/ha to raise the available-P level in the soil by 1 kg/ha.

After initial cultivation and cropping, native levels of available-P in soil are quite low. The farmer may opt to bring up the available-P levels immediately or over a period of years. After levels have reached a point (to be discussed later) where crop yields do not increase with fertilizer-P additions, the recommendation to the farmer may be either: (1) apply only enough fertilizer-P to replace the P removed by the crop, a "maintenance" application, or (2) apply no more fertilizer-P until available-P levels drop to the point where a yield response to added P is obtained. Option (1) provides the farmer with some insurance against extreme dry or wet years when the crop's ability to take up P is reduced.

Soil testing varies by state, with some states having a strong state-run soil test program, while others depend entirely on private laboratories. In recent years, the role of the private lab in soil testing has increased. Recommendations for fertilizer application are based, for the most part, on research conducted by state experiment stations and the information is disseminated by the state extension service in the form of published bulletins as well as farmer meetings.

The intensity of fertilizer application in a given area (watershed, county, etc) is a function of a number of variables: nutrient requirements of the crop and crop distribution, soil and climatic effects, economic farm conditions, distribution of full-time and part-time farmers and others. Indications are, that in recent years in the Great Lakes states, available-P levels in the soil have been increasing, and, in many instances, may be higher than necessary. Evidence to document such a trend is based primarily on statistical summaries of soil test data from state laboratories. There are a number of potential errors in the interpretation of such data: (1) not all farmers test their soil, and those that do may apply more fertilizer than the part-time farmer,

(2) state soil test summaries do not necessarily reflect conditions on farms where a private testing lab is used.

The relationship between plant available-P and that which is available to aquatic organisms, especially algae, is not readily apparent; however, an appreciation of basic soil science principles would indicate that they are positively correlated. This is supported by the work of Romkens and Nelson (1974) who found that plant available-P of runoff sediment was highly correlated with dissolved inorganic-P (DIP) in the runoff water. Therefore, an increase in available-P levels of watershed soils is likely to increase DIP levels in streams draining the watershed, although the impact is difficult to predict.

In light of these concerns, a study was initiated to investigate levels of available-P in agricultural soils in the Lake Erie drainage basin. The study had two major objectives:

(1) To survey actual field levels of available P in a county in Ohio and compare these with published soil test summary data for the same area

(2) To determine if similar data were available in other L. E. Basin states and to determine if soil test methods and recommendations varied significantly from state to state.

STUDY METHODS

1. Analysis of available-P in Defiance county soils

Defiance county, Ohio (Figure 1) was selected for study because it was representative of production agriculture in a large part of the LEWMS study area, the soils are representative of glacial till and lacustrine soils of the central and western region of the LE drainage basin, considerable supporting data was available from PLUARG Task C studies in the county, and the high level of cooperation from local county officials. The ASCS maintains a file of all cooperating land owners or operators in the county and this represents a high percentage of the farm community. Defiance county is undergoing a progressive soil survey and, on the basis of completed soil mapping, three townships in the lake plain region of the county (Mark, Delaware, and Richland) were selected, together with one section in Hicksville township located in the till plain region (Figure 2). The ASCS list for the areas selected were used to select a total of 60 farms, 6 in Hicksville, 17 in Delaware, 18 in Mark and 19 in Richland township. The farms represent about 10% of the cooperators in each township (except Hicksville), and were selected at random. All owners or owner-operators were contacted by mail to request permission to take soil sample and permission was granted in all cases.

At each farm, the occupant was asked to identify a field which represented a normal rotation in the area; for the most part, rotations encountered were corn-wheat-soybeans with a small amount of hay. Speciality crops were deliberately avoided. A composite soil sample (0-15 cm) was taken from the field; a minimum of 10 acres was sampled in each case and a minimum of 40 cores per field included in each sample. The samples were taken with a standard 3.5 cm dia. soil probe and placed in plastic bags for analysis. The sampled field was located on SCS maps and the dominant soil series identified. In those instances where the field was made up of more than one soil, care was taken to sample only one soil series. As a result, we are confident that

Figure 1. Lake Erie drainage basin

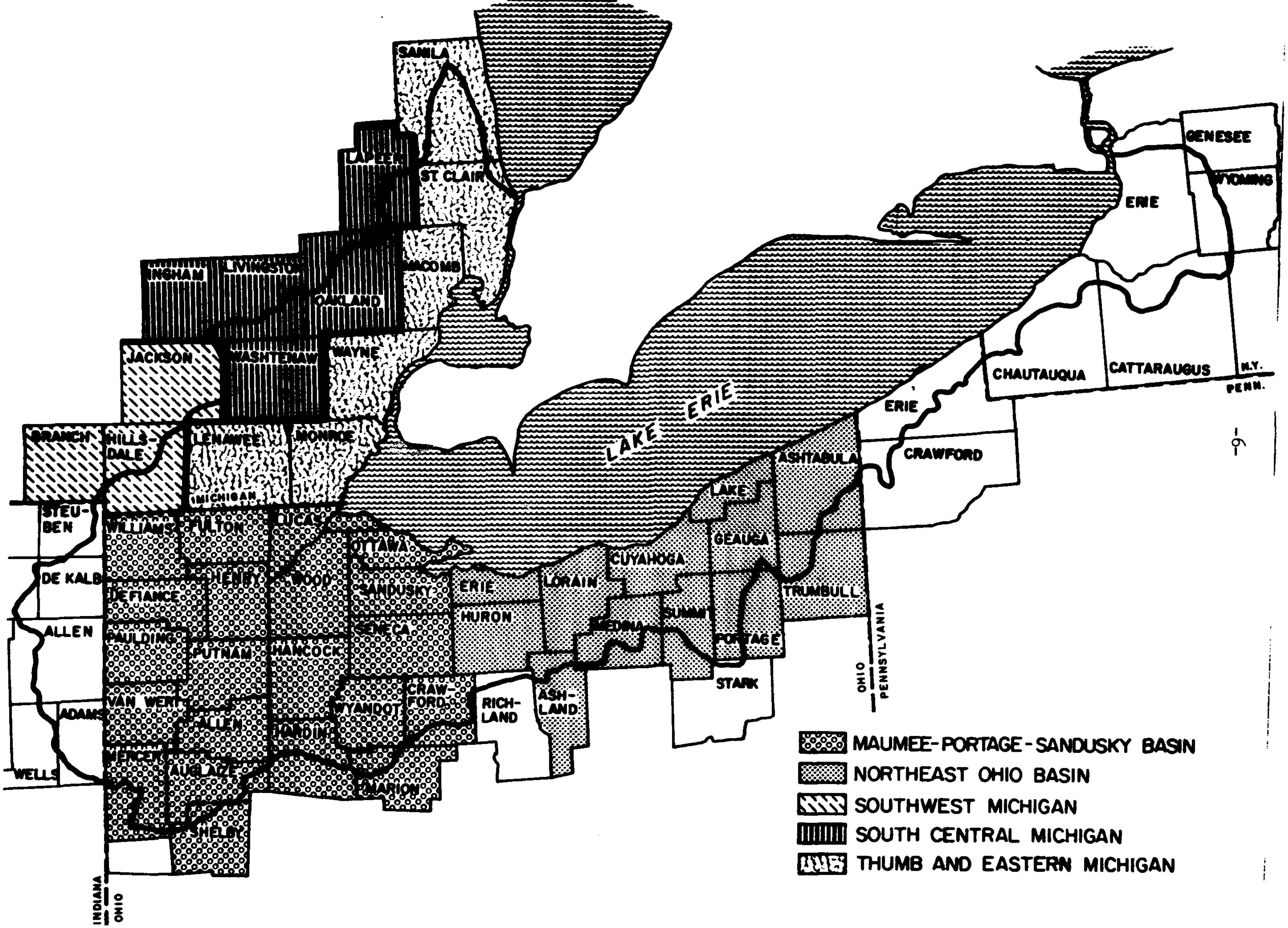
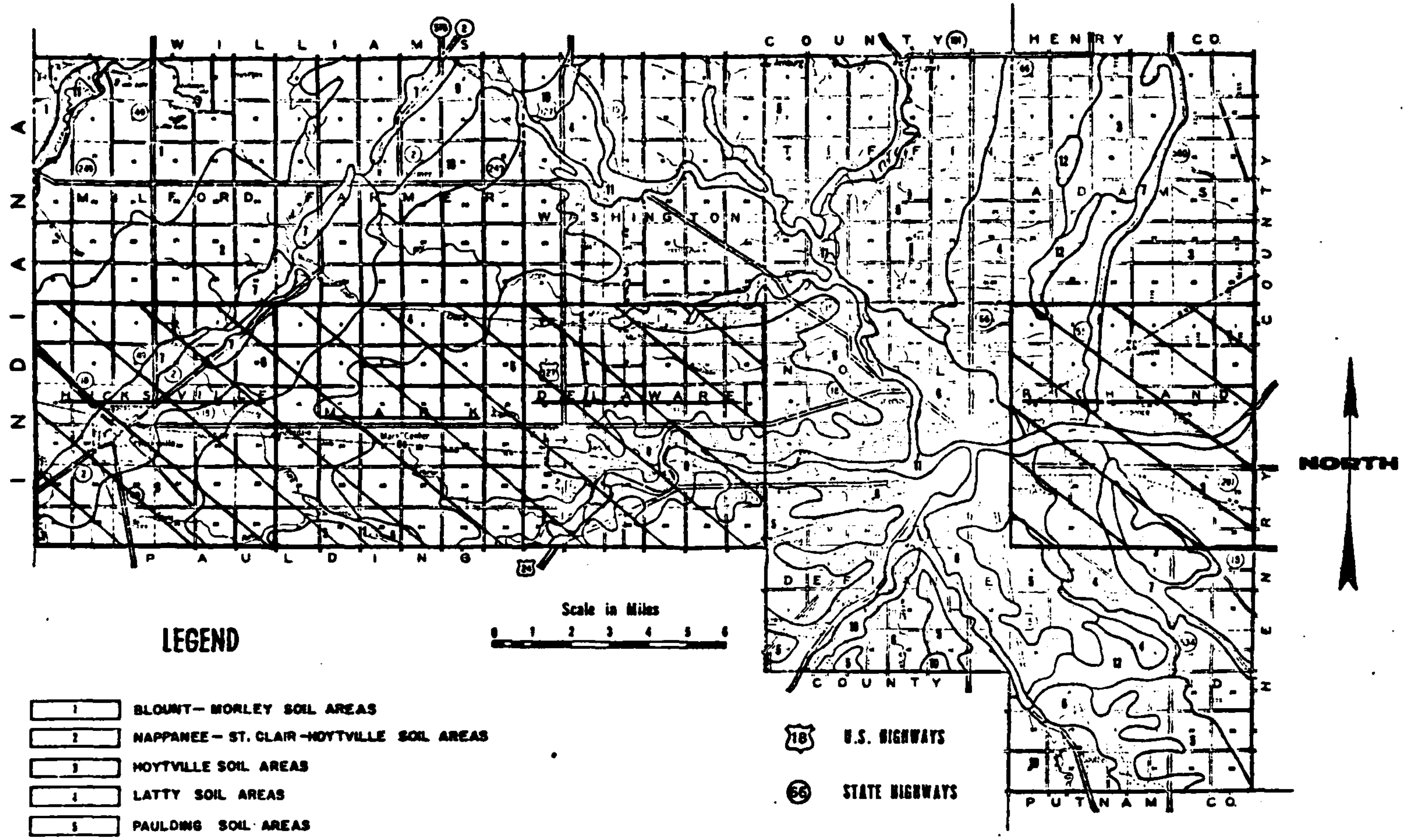


Figure 2.

GENERAL SOIL MAP OF DEFIANCE COUNTY



LEGEND

1	BLOUNT—MORLEY SOIL AREAS
2	NAPPANEE—ST. CLAIR—HOYTVILLE SOIL AREAS
3	HOYTVILLE SOIL AREAS
4	LATTY SOIL AREAS
5	PAULDING SOIL AREAS
6	ROSELMS—BROUGHTON—PAULDING SOIL AREAS
7	BELMORE—HANEY—DIGBY SOIL AREAS
8	TUSCOLA—KIBBIE—COLWOOD SOIL AREAS
9	HASKINS—MERMILL SOIL AREAS
10	TOLEDO—FULTON—ABOITE SOIL AREAS
11	EEL—SHOALS—SLOAN SOIL AREAS
12	WAUSEON—TEDROW—RIMER SOIL AREAS

NOTE: The Soil Areas Listed Above Are Described On The Reverse Side

18 U.S. HIGHWAYS

66 STATE HIGHWAYS

ACKNOWLEDGEMENTS

This map has been prepared from soil information acquired through a systematic reconnaissance survey for the purpose of preparing the soil resource area map for the Water Resource Inventory Report of the Maumee River Watershed in cooperation with the Ohio Division of Water. Individual farm soil surveys by the U. S. Soil Conservation Service provided much valuable information.

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the samples taken were homogeneous with respect to soil series.

The soil samples were returned to the laboratory, air-dried, ground and screened (the > 2 mm fraction was retained) and mixed thoroughly. Total-P was determined by perchloric acid digestion (Sommers and Nelson, 1972) and available-P by the Bray P1 method (Bray and Kurtz, 1945). The available-P method used is the same as that used by the Ohio State University Soil Test Laboratory and our method was checked against theirs by the use of two soil standards employed by Ohio State for many years, representing high and low values. Our values were within 5% of theirs.

2. Ohio Soil Test Summary

In 1961 and again in 1971, statistical summaries were made of the results of all soil samples submitted to the Ohio State University Soil Test Lab (Jones and Musgrave, 1963; Follett and Trierweiler, 1973). The 1976 data is organized by county and separate field crop, turf and horticultural samples. Turf and horticultural samples tend to be higher in available-P than field crop soils but represent a fairly small acreage. In addition, many of the horticultural samples are for greenhouse soils. In highly urbanized counties, turf soil levels may become significant; however, for this study only field crop summaries were used.

3. Data from other states

State extension service personnel were contacted in all of the LE states and Ontario. Only Michigan in addition to Ohio was able to provide a statistical summary of soil test data. Other states either did not have a computer-based system to process their data or did not keep summaries of their data. Ontario does keep its data on the computer, but there was insufficient time to get access to their system; however, published summaries were used instead.

One of the objectives of this study was to determine if there were significantly different methods of analysis and interpretation in each of the LE states and Ontario. To this end, personal contacts and published literature were used. A very useful publication (Genson and Schulte, 1975) compared recommendations by several states in the north-central region for similar soils and crops and some of their findings are reported.

RESULTS AND DISCUSSION

1. Defiance county soil analysis

Total and Bray P1 "available" P values are given in Table 1 for each township sampled. Total P levels of the till plain soils (Hicksville township) were significantly lower than those of the lake plain. Values for the three lake plain townships were about the same. The lower values for the Blount soil may be due to differences in parent material (till versus lacustrine), more erosion on the more sloping Blount, or the lower clay content of Blount compared with the lake plain soils. The overall mean value of ~700 ug/g is similar to values found in PLUARG Task C study (Logan, 1976).

Available-P levels varied widely in all areas and within soil types. Values found were, for the most part, similar to those in the 1976 soil test summary for Defiance county (Table 3). Several high values (> 100 ug/g) were found. A value of 280 ug/g was found on Tedro soil, a high organic matter sand, which may be responsible, in part, for the high value. The other two values were on Hoytville. One sample, showed a high total P value while the other was normal. The sample with high total P may be due to large applications of manure over time.

In general, it would appear that actual soil analysis of farmers' fields chosen at random gives similar results as compared to that given by summarized the results of submitted soil samples. Although Defiance county only represents a small percentage of the total LE drainage area in Ohio, it does appear that there are no major biases associated with the Ohio State soil test summary. We attempted to identify which of the owner-operators of farms sampled had used Ohio State soil test. This was not possible, however, because a single operator may be farming in several parts of the county and may submit soil samples from any or all of his operations. He usually identifies his samples by number which has meaning only to himself. The computer print-out gives his results by number only.

Table 1. Total-P and Bray P1 available-P values for soils in Defiance county, Ohio (Mean of duplicate samples analyzed)

Soil series	Total-P	Bray P1 available-P
	----------ug/g------------	
Hicksville Township		
Blount	372.42	13.72
Blount	424.04	13.94
Blount	479.35	18.81
Blount	523.60	28.32
Blount	457.23	8.85
Pewamo-Blount	475.66	11.56
Mean	455.38	15.87
S. D.	51.98	6.93
Delaware Township		
Latty	943.96	18.37
Roselms-Paulding	804.71	23.01
Latty	674.78	23.67
Mermill-Ottokee-Roselms	401.92	9.96
Paulding	781.72	21.46
Paulding	505.17	11.50
Roselms	615.78	11.29
Shinrock-Genesee	567.85	19.25
Paulding	741.15	17.48
Latty	766.96	32.08
Roselms	719.03	14.82
Paulding	1006.64	55.98

Table 1 . (Continued)

Soil series	Total-P	Bray P1 available-P
	---------ug/g------------	
Delaware Township		
Latty	781.71	14.16
Paulding-Roselms	851.77	27.88
Paulding	833.33	30.75
Paulding-Roselms	667.40	9.96
Roselms	483.04	8.63
Mean	714.52	20.60
S. D.	162.36	11.69
Mark Township		
Hoytville	707.97	14.38
Hoytville	807.52	17.26
Hoytville	1225.08	71.46
Latty	626.85	21.90
Roselms	486.73	13.28
Tedro	737.47	280.75*
Latty	700.59	20.14
Hoytville	696.90	13.72
Latty	763.28	16.60
Lenawee	848.08	23.90
Latty	752.21	13.72
Latty	800.15	19.91
Del Ray	682.16	25.44
Latty	556.79	13.28

Table 1. (Continued)

Soil series	Total-P	Bray P1 available-P
	---------ug/g---	----------
Mark Township		
Hoytville	416.67	27.00
Latty	722.72	17.04
Roselms	453.54	11.73
Nappanee	855.46	24.12
Mean	702.23	38.57 (21.46)*
S. D.	152.37	62.55 (13.75)*
Richland Township		
Hoytville	837.02	46.91
Nappanee-Mermill-Rawson	792.77	26.99
Hoytville	892.33	51.11
Hoytville	825.96	32.30
Hoytville	755.85	165.49*
Mermill	213.87	53.99
Hoytville	792.78	32.97
Hoytville	549.41	31.42
Nappanee	707.97	33.41
Hoytville	822.27	28.10
Hoytville	645.28	11.73
Oshtemo	409.30	17.70
Hoytville	1485.99	269.47*
Hoytville	844.40	26.99
Hoytville	682.16	29.20

Table 1 . (Continued)

Richland Township

Soil series	Total-P	Bray P1 available-P
	---------ug/g------------	
Del Ray-Haney-Lenawee	527.29	22.79
Hoytville	815.59	21.68
Hoytville	604.72	23.23
Nappanee	737.46	26.11
Mean	733.97	50.08 (30.39)*
S. D.	249.99	62.39 (11.24)*
Overall Mean	691.08	34.04 (23.28)*
Overall S. D.	198.82	50.26 (12.56)*

* Available-P values > 100 ug/g. Means and S. D. in parentheses were calculated after omitting these values.

The available-P results were grouped by range and compared with the 1971 and 1976 soil test summary results (Table 2).

Table 2 . Distribution of available-P levels in Defiance county according to soil test summary and project survey

	Percent of samples in each category					
	<10*	10-19	20-29	30-59	60-89	>89
Soil test summary 1971	9	20	26	30	11	5
1976	4	16	18	40	13	9
Project survey	0	3.0	26.7	46.7	10.0	13.3

* Available P in pounds/acre

The results of our limited survey fell into approximately the same distribution as found in the summaries. The major difference was the lower number of samples found in the 10-19 lb/ac range, with higher percentages in the 20-29 and 30-59 lbs/ac ranges. This would also indicate that soil testing summary data does not appear to be biased upwards.

Regression analysis was made between total and available-P, but R^2 was only 0.21. Available-P values appear to be more a function of management than other factors.

2. Ohio Soil Test Summary

The Ohio counties which have watersheds draining primarily into Lake Erie were divided into two groups: those in the Maumee-Portage-Sandusky Basins and those to the east. This distinction is arbitrary but tends to separate the two regions on the basis of soils and land use. These separations may be tested more rigorously when the LEWMS land use and soil data system is available. The Maumee-Portage-Sandusky is characterized by high agricultural land use (primarily cultivated row crops) and high-lime glacial tills and lacustrine sediments. In the eastern region, we find more urban land use, higher percentages of the agriculture in hay and pasture and grading from till to sandstone and shale derived soils.

Table 3 gives the mean available-P content of the LE Basin counties for 1961 (Jones and Musgrave, 1963), 1971 (Follett and Trierweiler, 1973) and 1976. Both subbasins show an increase from 1961 to 1971 of 50 to 100% with the greatest increase in the eastern area. From 1971 to 1976 there was an 18% increase in the Maumee-Portage-Sandusky region and a 9% increase in the east, indicating that although available-P levels are continuing to increase, the rate of increase has slowed. In the Maumee-Portage-Sandusky area, Paulding county had the lowest mean levels in all three years, while Fulton and Lucas counties were the highest. Sandusky and Henry counties gave some of the most significant increases.

In the eastern area, most of the increases occurred in the period 1961-1971 with significant increases occurring in only a few counties from 1971 to 1976. The slower rate of increase may be attributable to the lower intensity of agriculture in the area with subsequent lower rates of fertilizer application and the higher capacity of soils in the area to render fertilizer phosphorus unavailable. In several of the more urbanized counties, field crop sample numbers were quite low and statistical summary should be interpreted with caution. A case in point was Cuyahoga county which only had two samples submitted in 1976.

A better picture of the changes in available-P from 1971 to 1976 can be obtained by looking at the percent distribution of samples falling into various ranges (Table 4). In the Maumee-Portage-Sandusky Basin there were decreases in ranges <30 pounds/acre and increases in all ranges > 30 pounds/acre. Since 30 pounds/acre is the critical value between plant deficiency and sufficiency, this shift is not unusual. The major shift appears to be from the 10-19 pounds/acre to the 30-59 pounds/acre; this latter range has the highest percentage of values and accounts, to a large extent, for the means in Table 3 .

In the eastern Basin, shifts in the ranges from 1971 to 1976 were small, with the biggest change being a decrease in the <10 pounds/acre range. The 30-59 pounds/acre range had the highest percentage of samples, as in the Maumee-Portage-Sandusky Basin. The data for the state as a whole (Table 4) is very similar to that of the eastern Lake Erie Basin. Most counties in the state are experiencing small increases in available-P levels, but the increase is greatest in the Maumee-Portage-Sandusky Basin counties.

If we look at individual counties, we see that Fulton and Lucas have the highest percentages in the >89 pounds/acre range, and this may be due, in part, to the dairy and poultry industries in Fulton county and the orchards in Fulton and Lucas counties as well as vegetable farming.

Table 3 . Ohio soil test summary of available-P values for field crop soils (1961, 1971, 1976).

County	Bray P1 available-P (pounds/acre)*		
	1961	1971	1976
Maumee-Portage-Sandusky Basins			
Williams	24	42	55
Fulton	43	64	76
Lucas	82	67	70
Wood	26	50	52
Henry	21	50	61
Defiance	24	37	44
Mercer	30	36	51
Marion	25	33	45
Crawford	21	36	46
Sandusky	23	52	60
Paulding	19	29	33
Putnam	25	49	55
Hancock	25	43	50
Van Wert	31	40	40
Allen	21	35	47
Hardin	22	41	40
Auglaize	21	31	44
Wyandot	22	37	46
Seneca	19	37	40
Ottawa	27	49	56
Mean	27.55	42.90	50.55
S. D.	13.89	10.24	10.54

Table 3. (Continued)

County	Bray P1 available-P (pounds/acre)*		
	1961	1971	1976
	N. E. Ohio (Lake Erie Drainage Basin)		
Erie	31	40	52
Huron	21	51	53
Lorain	14	26	32
Ashland	22	35	43
Medina	20	30	33
Ashtabula	14	28	29
Cuyahoga†	-	68	11
Summit	24	42	55
Portage	21	37	43
Geauga	10	32	33
Lake	15	62	49
Trumbull	19	34	34
Mean	19.18	40.42 (37.9)†	38.9 (41.45)
S. D.	5.78	13.37 (10.65)	12.73 (9.66)

* To convert to ug/g, divide by 2.

† Values in parentheses were calculated after omitting Cuyahoga county which had very few samples.

Table 4 . Percent distribution of Ohio State Soil Test Laboratory available-P results for 1971 and 1976 by counties in Lake Erie Drainage Basin.

County	1971						1976					
	<10†	10-19	20-29	30-59	60-89	>89	<10	10-19	20-29	30-59	60-89	>89
	Maumee-Portage-Sandusky Basins											
Williams	3	15	20	38	17	7	2	11	17	41	19	11
Fulton	1	5	8	35	31	21	0	2	7	26	34	32
Lucas	2	7	10	33	23	26	1	6	7	30	26	30
Wood	5	10	15	38	20	12	1	6	13	47	23	9
Henry	1	10	20	36	19	14	0	6	7	42	29	16
Defiance	9	20	26	30	11	5	4	16	18	40	13	9
Mercer	5	22	20	38	11	3	1	10	14	46	18	10
Marion	7	23	24	35	9	3	2	13	21	44	14	7
Crawford	6	22	22	36	12	3	2	10	19	48	13	8
Sandusky	5	11	15	34	21	14	3	9	12	30	27	19
Paulding	8	34	23	27	6	3	4	24	26	38	5	3
Putnam	4	13	16	36	18	13	1	5	17	43	21	13
Hancock	2	14	22	40	16	6	1	9	14	47	21	9
Van Wert	3	14	22	44	13	4	2	17	16	50	10	6
Allen	5	19	24	42	8	3	1	12	15	46	20	7
Hardin	4	21	20	35	13	8	2	17	20	47	11	4
Auglaize	6	25	25	33	8	2	2	11	20	43	18	5
Wyandot	6	17	24	39	11	4	2	12	18	43	17	8
Seneca	7	23	19	33	12	6	2	16	22	42	13	3
Ottawa	7	31	15	16	12	9	2	8	15	31	29	15
Mean	4.8	17.8	19.5	34.9	14.6	8.3	1.8	11.0	15.9	41.2	19.1	11.2
S. D.	2.3	7.6	4.9	5.9	6.1	6.6	1.1	5.2	5.1	6.8	7.4	8.0

Table 4. (Continued)

County	1971 <10†	10-19	20-29	30-59	60-89	>89	1976 <10	10-19	20-29	30-59	60-89	>89
N. E. Ohio (Lake Erie Drainage Basin)												
Erie	8	14	19	38	16	4	5	11	16	31	24	13
Huron	9	21	17	22	7	24	5	19	18	32	9	16
Lorain	16	32	23	22	5	2	9	28	19	34	5	4
Ashland	6	24	21	34	11	4	5	19	19	33	15	10
Medina	14	29	17	30	7	3	11	30	19	27	7	5
Ashtabula	24	26	16	22	9	3	19	27	16	27	8	3
Cuyahoga*	39	13	4	9	9	26	50	0	50	0	0	0
Summitt	13	17	13	24	11	11	6	13	13	33	19	16
Portage	12	20	17	32	12	6	8	19	19	30	14	9
Geauga	18	23	16	30	9	3	11	27	20	27	12	4
Lake	17	11	13	19	13	26	14	29	10	10	22	14
Trumbull	13	25	17	29	13	4	12	27	15	32	8	5
Mean*	13.6	22.0	17.2	27.5	10.3	8.2	9.5	22.6	16.7	28.7	13.0	9.0
S. D.	5.1	6.3	3.0	6.0	3.2	8.7	4.4	6.7	3.1	6.7	6.4	5.1
Ohio	14	22	18	30	10	6	10	18	17	33	13	8

* Statistics exclude Cuyahoga county data.

† Available-P in pounds/acre.

3. Data from other states

Soil test data from Michigan was available from published reports (Warncke and Doll, 1973; Doll et al., 1972) and print-outs of individual county data were made available by Dr. Daryl Warncke, Michigan State University. Published data was organized on the basis of geographic regions (Figure 1), three of which are in the Lake Erie Basin: Thumb and eastern Michigan (Lenawee, Monroe, Wayne, Macomb, St. Clair, Sanilac counties); south central Michigan (Lapeer, Oakland, Livingston, Ingram, Washtenaw) and south west Michigan (Jackson, Branch, Hillsdale).

Table 5 gives mean and percent distribution of samples on organic soils from 1962 to 1972. Increases over the period have been experienced in most areas, especially during the period 1967-1971. By 1972, significant percentages of the samples were giving available-P (Bray P1 method) levels >100 pounds/acre. Organic soils because of their chemical nature are high in total P and tend to be high in available-P; however, the increases with time seen here are a result of the fertilization practices on these intensely farmed soils.

Available-P levels vary by soil texture as well as soil type. This is illustrated by the data in Table 6 for 1962, 1967 and 1971 which has been organized by management groups which reflect soil texture. Clay soils react more strongly than sands and tend to keep available-P levels lower than coarser-textured soils. In all cases, however, available-P levels increased with time.

The distribution of soil samples by available P ranges for Lake Erie counties in Michigan is given in Table 7 for the period 1962-1976. With the exception of Oakland county, most counties showed a decrease in the 0-9 pounds/acre range with time, and small decreases in the 10-19 pounds/acre range except for Oakland and Macomb. The 20-39 and 40-69 pounds/acre ranges had the highest percentages of samples and shifts with time were not readily apparent, some counties showing increases while others decreased or remained the same. The range of maximum frequency corresponds somewhat with the Ohio data, but in general is somewhat higher.

Michigan gives several ranges above that of Ohio, and a number of counties had significant numbers of samples in these high ranges. There appeared to be somewhat of a tendency for these ranges to increase with time, but the trend was not strong or consistent.

Doll et al (1972) report that mean available-P values (pounds/acre) for 1962 and 1972 were: Thumb and eastern Michigan, 40 and 67; south central Michigan, 105 and 116; south west Michigan, 49 and 70. These mean values are all higher than those obtained for Ohio for similar periods (1961 and 1971). The differences may be attributed to: 1) a greater diversity of soils in Michigan with more organic and sandy soils which tend to have high available-P levels 2) more intense agriculture with high percentage of vegetable crops and 3) differences in soil test recommendations (to be examined in next section). The high frequency of extremely high ranges can be attributed to 1) and 2) above.

Lake Erie counties in Ontario were identified (Figure 3) and published reports of the University of Guelph (1971, 1974, 1975, 1976) used to determine available-P status of Ontario soils. The data used is a summary of soil test results from the Ontario soil test service at the University of Guelph, Guelph, Ontario. Ontario uses the Olsen 0.5 M $NaHCO_3$ (sodium bicarbonate) extraction to estimate available-P. Values obtained by this method are similar to those given by the Bray P1 method used in most U. S. Lake Erie states, but are somewhat higher. This should be kept in mind when comparing the Ontario data with that on the U. S. side of the Basin. Table 8 gives mean available-P levels for Lake Erie Basin counties for the period 1970-1975. The results show that, in contrast to Ohio and Michigan, there has been no change in available-P levels. Only Norfolk county, a major specialty crop area, has what would be considered high available-P levels.

Table 5. Distribution of available phosphorus values for the organic soils of four regions of Michigan for 1962, 1967, 1971 and 1972 (Warncke and Doll, 1973).

			Range in Phosphorus Levels (pounds/acre)							
Region	Year	Mean pounds/acre	0-9	10-19	20-39	40-69	70-99	100-149	150-199	> 200
			% of samples							
Thumb and Eastern Michigan	1962	27	12.9	34.1	37.6	10.6	1.2	2.4	1.2	0.0
	1967	61	11.3	19.7	21.1	31.0	5.6	5.6	1.4	4.2
	1971	147	6.9	13.8	10.3	13.8	10.3	10.3	13.8	20.7
	1972	103	11.4	8.6	22.9	8.6	11.4	14.3	5.7	17.1
South Central Michigan	1962	38	22.9	23.7	18.8	16.7	8.6	6.1	3.8	0.0
	1967	57	12.0	16.4	16.7	21.1	15.9	14.1	3.6	0.3
	1971	78	8.4	11.8	19.8	19.8	16.0	9.9	4.9	9.5
	1972	57	3.9	14.1	25.2	24.8	19.4	9.2	1.9	1.5
South West Michigan	1962	39	25.0	10.4	20.8	27.1	10.4	4.2	2.1	0.0
	1967	50	14.0	28.0	20.0	18.0	8.0	6.0	2.0	4.0
	1971	53	8.2	22.4	24.5	28.6	0.0	10.2	2.0	4.0
	1972	94	1.4	10.0	15.7	20.0	20.0	11.4	11.4	10.0
Average for Michigan	1962	43	17.7	23.9	22.3	15.9	8.2	5.0	6.2	0.6
	1967	60	13.1	16.7	16.7	21.0	13.5	12.8	4.1	2.0
	1971	84	7.7	11.5	16.9	20.4	13.9	15.1	5.8	8.8
	1972	79	5.2	11.7	18.8	19.9	16.1	14.0	8.2	6.1

Table 6 . Average available-P values for each mineral soil management group for lower Michigan for 1962, 1967 and 1971 (Doll *et al*., 1972).

Soil Management Group (a)	Year	Phosphorus
	1962	20
1	1967	39
	1971	41
	1962	24
2	1967	34
	1971	51
	1962	41
3	1967	51
	1971	87
	1962	56
4	1967	80
	1971	101
	1962	59
5	1967	81
	1971	116

(a) Soil management group 1 is comprised of clay soils; 2 is clay loams, loams, sandy clay loams, and similar soils; 3 is sandy loams; 4 is loamy sands; and 5 is sand soils.

Table 7 . Percentage distribution of soil test samples by available-P range (pounds/acre) in Michigan counties draining Lake Erie (1962-1976).

County	Year	Range in Phosphorus Levels (pounds/acre)								
		0-9	10-19	20-39	40-69	70-99	100-149	150-199	200-299	>300
		% of samples								
Sanilac	1962	40.9	37.9	16.4	3.8	0.6	0.4	0.0	0.0	0.0
	1967	11.1	24.4	37.9	19.8	4.7	1.5	0.3	0.2	0.1
	1970	17.2	32.9	27.1	15.1	3.7	2.2	1.1	0.5	0.1
	1975	5.0	11.9	27.8	29.3	15.5	8.2	0.7	1.2	0.5
	1976	6.0	14.1	29.6	27.6	13.1	6.4	1.7	0.9	0.6
St. Clair	1962	25.9	36.5	30.6	1.2	1.2	4.7	0.0	0.0	0.0
	1967	14.9	22.5	31.6	17.1	7.0	2.5	3.5	0.6	0.3
	1970	11.6	24.7	35.9	12.0	8.5	5.8	0.4	1.2	0.0
	1975	13.3	16.4	19.8	18.1	11.9	8.5	3.4	6.1	2.4
	1976	6.8	14.9	27.0	27.0	9.5	6.1	4.1	3.4	1.4
Macomb	1962	15.4	16.2	17.1	14.5	13.7	13.7	7.7	1.7	0.0
	1967	6.0	15.3	19.7	16.4	10.4	8.7	8.2	4.4	10.9
	1970	13.1	19.7	19.7	17.8	10.0	9.3	4.2	1.9	4.2
	1975	5.3	15.6	18.9	15.6	9.5	10.6	5.8	9.7	8.9
	1976	6.6	12.8	21.4	12.1	8.3	12.8	5.2	13.8	7.2
Lapeer	1962	16.7	29.6	33.6	12.6	4.8	2.2	0.4	0.0	0.0
	1967	22.5	28.8	30.4	12.9	3.0	1.8	0.4	0.2	0.0
	1970	9.8	19.5	28.9	25.4	10.2	4.3	0.8	0.8	0.4
	1975	3.4	13.3	37.2	21.8	9.2	7.2	2.4	4.4	1.0
	1976	7.4	13.9	24.3	30.9	11.3	6.5	3.5	2.2	0.0
Oakland	1962	9.4	7.5	28.3	30.2	15.1	9.4	0.0	0.0	0.0
	1967	8.1	9.9	20.7	25.2	21.6	8.1	5.4	0.9	0.0
	1970	9.0	12.8	19.9	18.6	10.3	14.1	4.5	5.8	5.1
	1975	4.8	9.2	15.6	18.8	14.4	11.5	9.4	10.8	5.5
	1976	10.0	10.3	14.2	17.1	10.7	12.1	9.3	8.9	7.5

Table 7. (Continued)

County	Year	0-9	10-19	20-39	40-69	70-99	100-149	150-199	200-299	>300
		Range in Phosphorus Levels (pounds/acre)								
		% of samples								
Livingston	1962	12.5	18.8	12.5	50.0	0.0	0.0	6.3	0.0	0.0
	1967	9.2	20.1	32.2	26.4	7.1	3.3	1.7	0.0	0.0
	1970	6.3	12.3	34.3	30.1	9.9	5.1	0.9	0.6	0.3
	1975	3.6	7.5	26.2	28.2	19.0	8.2	3.0	1.0	3.3
	1976	7.0	13.1	26.6	22.5	17.2	7.4	3.7	2.5	0.0
Washtenaw	1962	0.0	0.0	0.0	33.3	22.2	33.3	11.1	0.0	0.0
	1967	19.5	21.1	24.2	15.6	4.7	3.1	9.4	2.3	0.0
	1970	17.6	16.2	22.1	16.2	7.4	10.3	2.9	4.4	2.9
	1975	7.4	13.6	16.6	18.8	12.8	11.4	8.2	8.4	2.7
	1976	7.1	9.6	18.6	16.7	14.7	10.9	7.7	6.4	8.3
Wayne	1962	6.3	8.9	10.1	24.1	16.5	17.7	13.9	1.3	1.3
	1967	1.8	10.7	12.5	21.4	7.1	19.6	16.1	10.7	0.0
	1970	10.6	19.7	18.2	18.2	12.1	9.1	3.0	6.1	3.0
	1975	6.8	6.0	13.5	15.8	18.8	19.5	6.0	9.0	3.4
	1976	0.0	8.4	13.3	22.9	13.3	12.0	9.6	9.6	10.8
Hillsdale	1962	0.0	33.3	16.7	33.3	16.7	0.0	0.0	0.0	0.0
	1967	13.3	33.3	26.7	6.7	0.0	13.3	6.7	0.0	0.0
	1970	3.2	16.1	19.4	25.8	22.6	12.9	0.0	0.0	0.0
	1975	0.0	3.7	14.8	29.6	3.7	22.2	7.4	11.1	7.4
	1976	0.0	8.6	17.1	42.9	11.4	8.6	2.9	5.7	2.9
Lenawee	1962	11.1	33.3	24.4	20.0	6.7	4.4	0.0	0.0	0.0
	1967	9.7	20.2	28.3	18.4	9.2	6.6	5.2	1.6	0.8
	1970	5.7	36.8	25.3	17.2	4.6	4.6	2.3	1.1	2.3
	1975	4.7	7.6	18.6	27.1	12.0	13.6	6.0	6.9	3.5
	1976	6.7	21.9	19.0	20.0	6.7	9.5	8.6	2.9	3.8
Monroe	1962	14.3	0.0	19.0	26.2	19.0	14.3	7.1	0.0	0.0
	1967	2.4	9.6	28.9	33.7	6.0	4.8	8.4	4.8	1.2
	1970	4.8	21.0	28.6	24.8	6.7	8.6	3.8	1.9	0.0
	1975	3.6	7.3	24.2	24.2	15.2	11.5	7.3	5.5	1.2
	1976	5.3	9.6	14.0	28.1	16.7	13.2	0.9	7.9	4.4

Figure 3. Ontario province with counties draining into Lake Erie shaded.

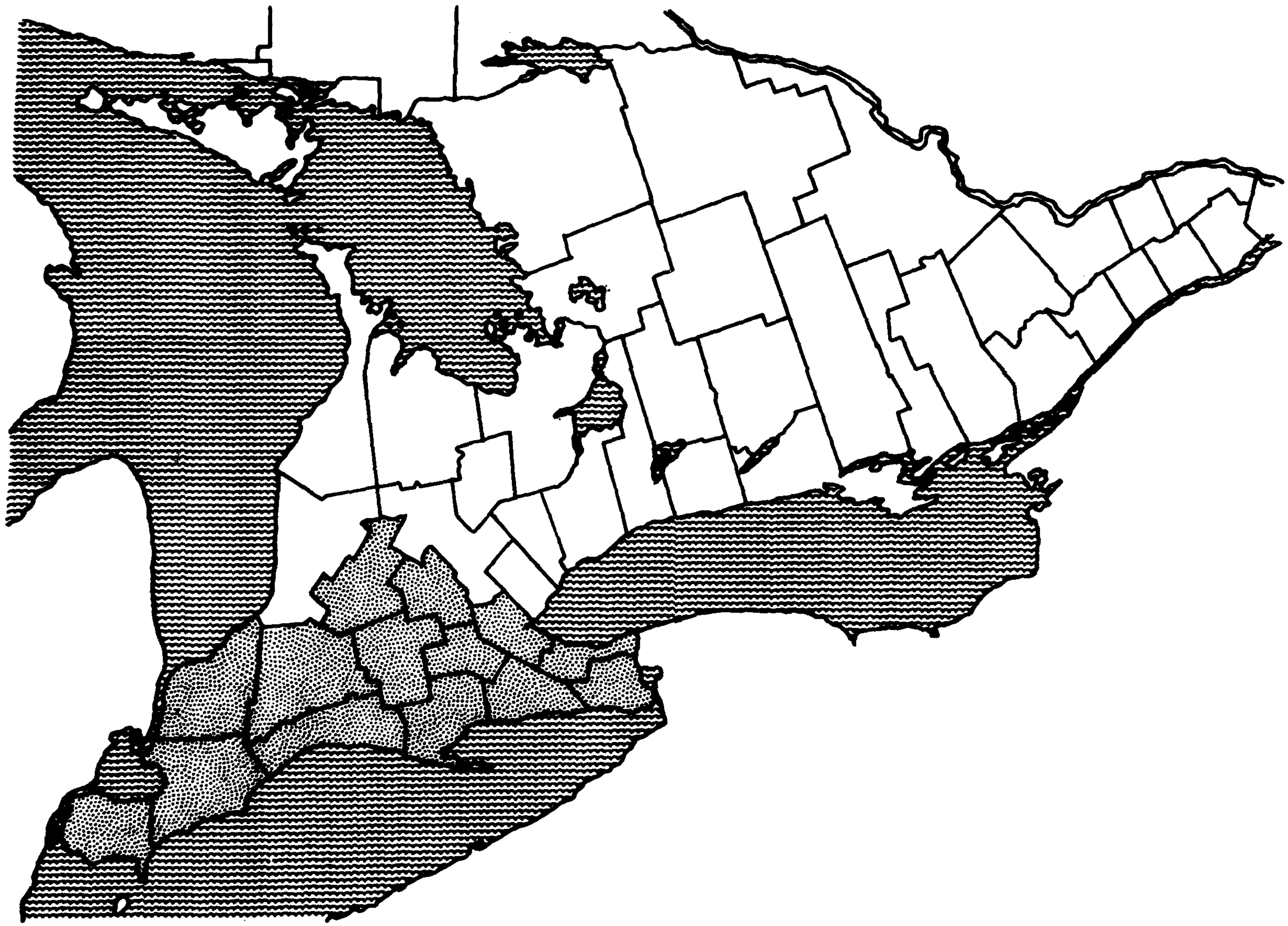

Table 8 . Available-P in Ontario soils in Lake Erie Basin counties

County	Available*-P (ug/g) 1970	1973	1974	1975
Brant	33	30	22	24
Elgin	30	31	29	23
Essex	40	41	32	34
Kent	25	30	25	27
Holdimand	14	19	17	16
Lambton	20	26	23	23
Middlesex	25	28	20	22
Niagara	18	33	22	22
Norfolk	49	56	55	51
Oxford	26	28	21	20
Perth	16	18	16	16
Waterloo	20	35	23	23
Wentworth	31	35	29	32

* Olsen's bicarbonate extraction

4. Phosphorus fertilizer recommendations among L. E. Basin states

Since the development of modern soil testing procedures in the period 1930-1950, attempts have been made to standardize soil test methods and fertilizer recommendations. Although this has been realized to some extent in the corn belt states for major crops (corn, wheat, soybeans) on mineral soils, there remain considerable differences in both procedures and recommendations. There are a number of ways in which methods may differ:

1) Extraction method
2) Definition of critical response level for available-P
3) Efficiency of fertilizer P applications (pounds per acre of fertilizer-P needed to raise available-P by one pound per acre)
4) Rate at which deficient soils should be built up to a sufficiency level
5) The need for a maintenance application (to replace P removed by crop) after available-P is at the sufficiency level

Genson and Schulte (1975) reviewed the procedures and recommendations of a number of corn belt states, three of which (Ohio, Michigan and Indiana) are in the L. E. Basin. Comparisons of recommendations based on various available-P levels were made for three soils which those states had in common (Miami, Blount and Russell). Of the three, the Blount soil is best representative of the L. E. Basin. The recommendations for alfalfa and corn are given in Table 9 . The table gives both the annual maintenance after buildup has been achieved and the 3-year total application. Of the three states, only Ohio uses a gradual and immediate buildup program, the difference being a large application the first year and smaller annual applications thereafter with the immediate buildup. The immediate buildup program would increase the risk of P loss in that year. If we look at the corn recommendations, we see that they are similar for all three states at the 13 pound/acre soil test level. At the intermediate range, Michigan's recommended application rate is higher than that of Ohio or Indiana. This would result in more Michigan soils testing $>$ 30 pounds/acre than Ohio or Indiana, a finding that is confirmed by the

Table 9. P fertilizer recommendations by soil test level (pounds P_2O_5/acre)

	Bray P1 (pounds/acre)		
	13	27	62
	Corn		
	80*	50	45
Ohio - Gradual	240†	150	135
	45	45	45
Ohio - Immediate	305	165	135
	80	60	30
Indiana	240	180	75
	75	75	25
Michigan	225	225	75
	Alfalfa		
	95	65	60
Ohio - Gradual	275	185	170
	60	60	60
Ohio - Immediate	340	175	170
	90	60	30
Indiana	270	180	75
	75	50	0
Michigan	250	175	25

* Annual application after initial buildup
† Total application for 3 years

Ohio and Michigan summary data (Tables 4 and 7). At the 62 pounds/acre soil test level, the Ohio recommendation is somewhat higher than either Indiana or Michigan which should lead to more rapid continued increase in available-P levels in Ohio than the other two states.

Examination of the alfalfa recommendations shows that at the low soil test level, the states are similar with the Ohio immediate buildup giving a higher 3-year total application. The rates at the intermediate soil test level are similar, but at the 62 pound/acre level, the Ohio recommendations are considerably higher than other states.

One factor which may contribute to the increase in available-P levels with time is whether or not maintenance applications are recommended. Genson and Schulte (1975) found that Indiana considered available-P level of 40 pounds P/acre to be optimum and recommended no further application when soil test was > 70 pounds/acre. Ohio considered a 30 pound/acre test to be optimum but recommended a maintenance application regardless of how high the soil test level was. Michigan gave no optimum level and recommended no further addition of P fertilizer when soil test was above 40-200 pounds/acre, the actual value depending on soil type and crop.

In Ontario, the Olsen bicarbonate extraction is used to measure available-P. This method gives somewhat higher values than the Bray P1 extraction. In Ontario, optimum available-P levels are established by crop and no P is applied above this value; there is no maintenance P application as used in Ohio. Optimum values (ug/g) are: sods and spring grains (except barley)- 14; peas and beans - 16; corn and barley - 21; winter grains, spring and winter seeded small grains - 23; hay and pasture - 51; vegetables - 61. The no maintenance recommendation is partly responsible for the lack of an increase in available-P levels in Ontario.

Information on New York and Pennsylvania was generally lacking or out of date. Pennsylvania contributes very little to the Lake Erie drainage and, in general, conditions would be expected to be similar to those in eastern Ohio. New York data was not attainable. The situation in New York is complicated by the use of private labs and the orchard and specialty crops in the Lake region.

5. Total P levels in L. Erie Basin soils

Much of the total P tributary load to Lake Erie is in the form of sediment-P and most of the sediment-P is of surficial soil origin. Total P load can be related to gross erosion by the equation:

Unit area total P loss (mg/ha) = Gross erosion (kg/ha) x total P content of surface soil (mg/kg) x P enrichment ratio x delivery ratio

By this equation, USLE estimates of soil loss can be used to predict P loss if the other factors are known. If one is only interested in determining management options for a given watershed, then delivery ratio can be held constant. Delivery ratio varies from 1 to 3 and is a function of clay content of the soil (the higher the clay content, the lower the enrichment ratio) and gross erosion (the higher the gross erosion, the lower the enrichment ratio).

Total P content of surface soil horizons varies from 100-2000 ugP/g soil with a mean of about 500 ugP/g. Factors which affect total P of soil are degree of weathering of the soil, P content of parent material, clay content and organic matter content. In general, total P content of soil is higher for clay soils and soils high in organic matter. Surface soils which have been seriously eroded are lower in total P since subsurface soil horizons tend to be lower in total P content.

Some data from the Maumee River Basin and other areas of the L. Erie Basin are available. These are summarized in Table 10 and represent the modern post-fertilization era.

Table 11 gives total-P values for a number of Ohio soils prior to 1920. Therefore, these values represent pre-fertilization levels.

While the data set is limited, the values indicate that increases in total P in the 40 years or so of active fertilization have had little effect on total P levels in soil. Net fertilizer additions (after allowing for erosion and crop removal) have probably increased total P levels by no more than 10%.

Table 10. Total-P content of some of Ohio and Indiana surface soils

Soil	Size Fraction	Total-P (ug/g) Range	Mean	S.D.	Reference
Defiance County, Ohio	whole soil	366-1241	774	251	Logan (1977)
Defiance County, Ohio	clay	738-1364	1003	271	Logan (1977)
<u>Indiana soils</u>					
silty clay loam	whole soil	-	705	40	Nelson et al (1977)
clay loam	whole soil	-	588	230	Nelson et al (1977)
silt loam	whole soil	-	424	137	Nelson et al (1977)
loam	whole soil	-	433	211	Nelson et al (1977)
sandy loam	whole soil	-	301	76	Nelson et al (1977)
loamy sand	whole soil	-	340	50	Nelson et al (1977)

Table 11. Total-P content of some Ohio surface soils by soil series

Soil	Number of Observations	Total-P (ug/g) High	Low	Mean
Brookston	17	960	600	810
Canfield	3	600	420	490
Crosby	2	540	480	510
Fox	2	640	370	505
Genesee	2	760	500	630
Lucas	6	640	380	465
Mahoning	2	460	430	445
Miami	23	640	260	482
Nappanee	4	820	360	575 (752)*
Paulding	4	890	630	763 (774)
Plainfield	7	490	270	391
Toledo	11	850	440	685
Wauseon	4	1180	380	713
Wooster	4	1040	400	678

* Modern values for same series, different location

CONCLUSIONS

1. Ohio soil test summary data appears to be a reasonable reflection of actual available-P levels in Lake Erie Basin counties of Ohio.

2. Available-P levels appear to be increasing in Ohio and Michigan but not in Ontario. The rate of increase has slowed in the 1970's compared to the 1960's.

3. Differences in available-P levels by state is related to soil and crop differences as well as fertilizer recommendations.

4. Available-P levels in Ohio, Michigan and Indiana will continue to increase slowly with present fertilizer recommendations.

5. Total-P levels in soils are higher in high clay soils and soils high in organic matter.

6. Total-P levels in soils do not appear to have increased significantly in the period since fertilization began in the U. S.

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